Validation of the TOLNet Lidars during SCOOP (Southern California Ozone Observation Project) using In-house and Centralized Data Processing

Thierry Leblanc[1], Kevin Strawbridge[2], Tim Berkoff[3], Guillaume Gronoff[3], Chris Senff[4], Andy Langford[4], John Sullivan[5], and Tom McGee[5]

[1] Jet Propulsion Laboratory, California Institute of Technology, Wrightwood, CA
[2] Environment and Climate Change Canada, Ontario, Canada
[3] NASA Langley Research Center, Hampton, VA
[4] NOAA-ESRL, Boulder, CO
[5] NASA-GSFC, Greenbelt, MD

and the extended SCOOP crew:
Mark Brewer, Patrick Wang, Pam Glatfelter, and Michelle Colgan ,
Bernard Firanski, Michael Travis,
Matthew Johnson, Guillaume Kirgis, Raul Alvarez,
Bill Carrion, Larry Twigg, Grant Sumnicht,
Michael Newchurch, and Shi Kuang

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SCOOP Campaign: *August 5-16, 2016*
JPL-Table Mountain Facility, California (elev. 2285 m)

- **Core participants: 5 tropospheric ozone lidars from TOLNet**
  - ***AMOLITE*** *from Environment and Climate Change Canada, PI: K. Strawbridge*
  - ***LMOL*** *from NASA Langley Research Center, PI: Tim Berkoff*
  - ***TMT*** *from Jet Propulsion Laboratory at TMF, PI: T. Leblanc*
  - ***TOPAZ*** *from NOAA-Earth System Research Laboratory, PIs: C. Senff and A. Langford*
  - ***TROPOZ*** *from NASA-GSFC, PIs: T. McGee and J. Sullivan*

- **Other contributors:**
  - *M. Newchurch (Univ. Alabama, Huntsville): Campaign refereeing support*
  - *S. Kuang (Univ. Alabama, Huntsville): Campaign refereeing support*
  - *M. Johnson (NASA AMES): Modeling support*
  - *B. Lefer and J. Kaye (NASA HQ): Campaign funding support*

- **Measurements and deployment:**
  - *5 x 50+ hours spread over 7 nights and days (incl. approx. 20 hours nighttime)*
  - *18 ECC ozonesondes launched by JPL-TMF group (1 to 6 launches per day)*
  - *5 x 24/7 surface ozone measurements*
  - *10+ hours of other lidar measurements from JPL-TMF (water vapor, stratospheric ozone and temperature, ceilometer)*

First Look: the dirty raw stuff....

All available 30-minutes-long lidar-ozonesonde-coincident profiles:

Coincidence criterion: First 30 minutes of each launch (+/- a few minutes)

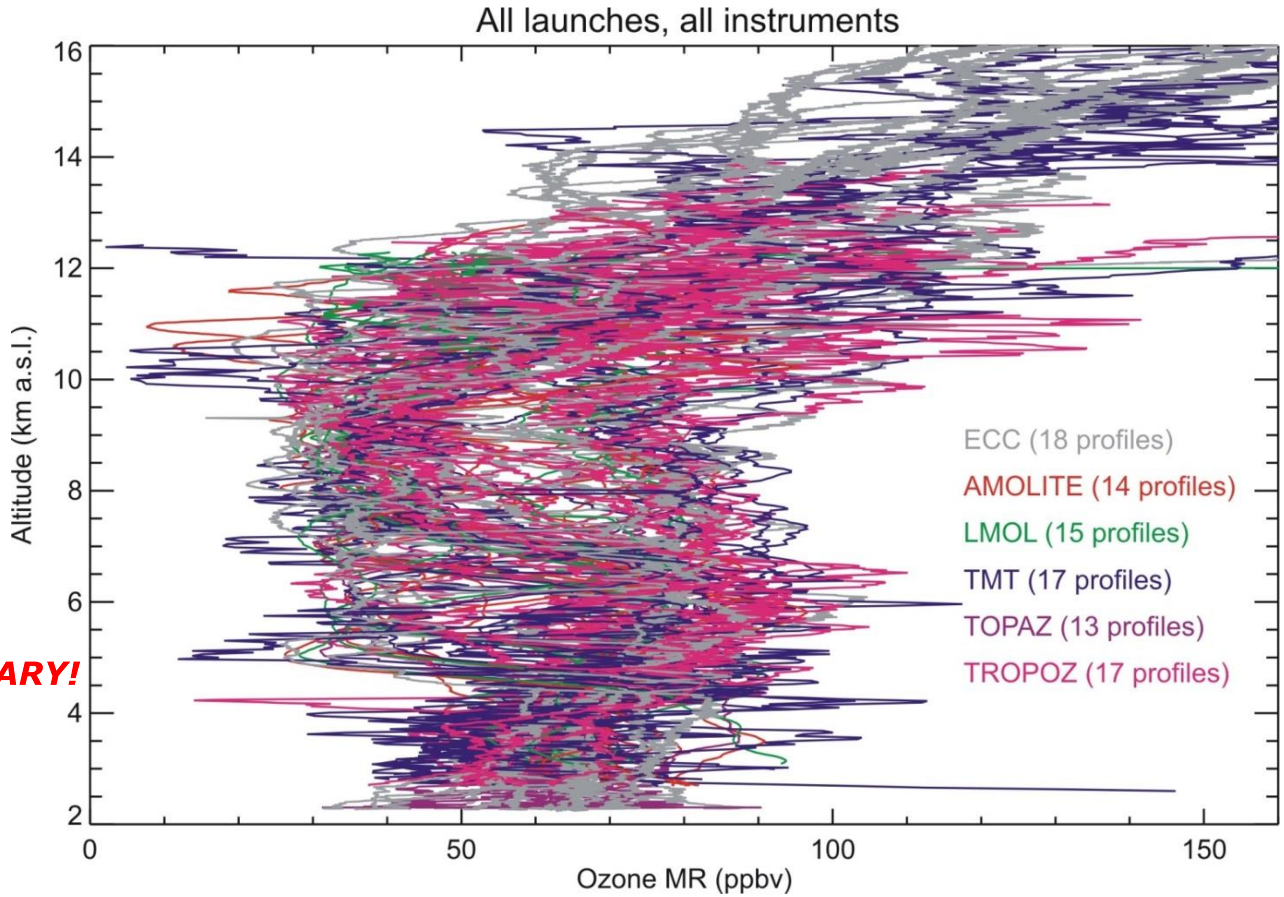
Figure shows:

- *Geophysical variability throughout campaign*
- *Extent of valid range for the various lidars*
- *Spread of measurements*
- *18 launches but not as many coincident lidar profiles due to logistical and operational constraints*

NOTE:

Today: showing only SCOOP "Level 2" data, i.e., PRELIMINARY!

The validated version ("SCOOP Level 3") will come out soon



➔ The rest of this work will show validation results using these PRELIMINARY SCOOP DATA ONLY and these coincidences only

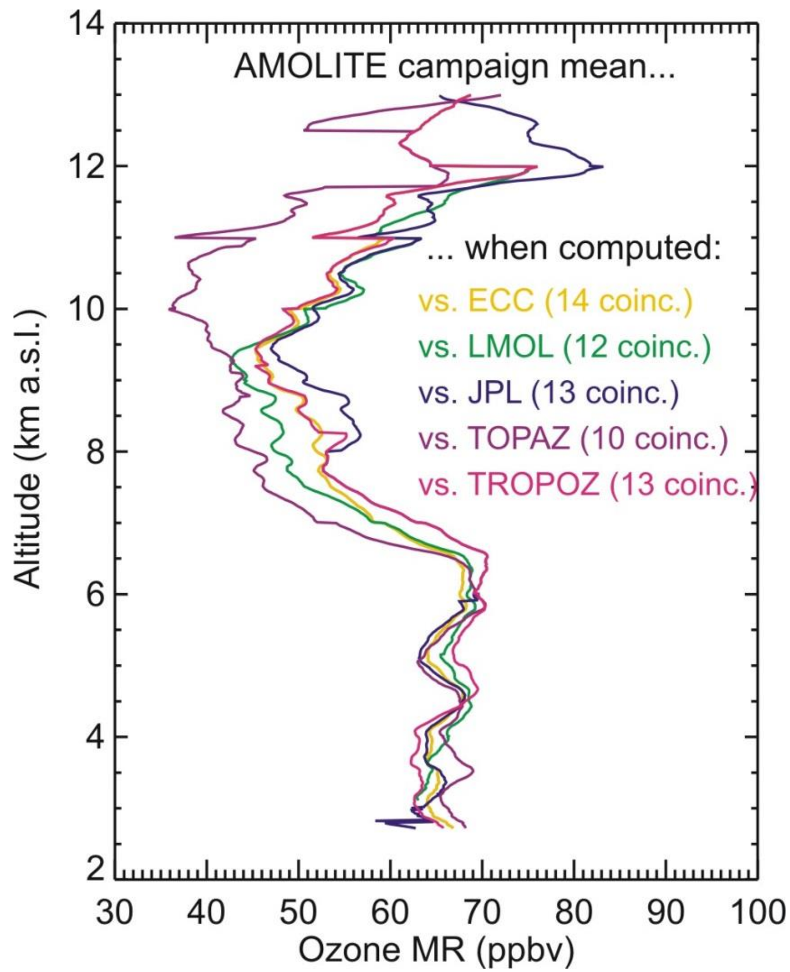
Optimizing the comparisons, step 1…

Are all instruments measuring the same atmosphere at the same time?

Figure shows example of AMOLITE "Campaign Mean" profiles against different coincident instruments:

- *"Campaign mean" is different whether it is compared against one instrument or another*
- *This combination of operational and geophysical constraints should be taken into account when interpreting observed discrepancies between 3 or more instruments*

Only 7 ECC launches during which all 5 lidars operated simultaneously



➔ Instruments will be compared with each other, but using one-to-one instrument coincidences in order to maximize comparison statistics

Optimizing the comparisons, step 2....

Do all instruments have the same capability to resolve thin vertical structures?

➔ **For this study, all lidar and ECC data were processed to yield the same vertical resolution:**
The "SCOOP vertical resolution scheme"

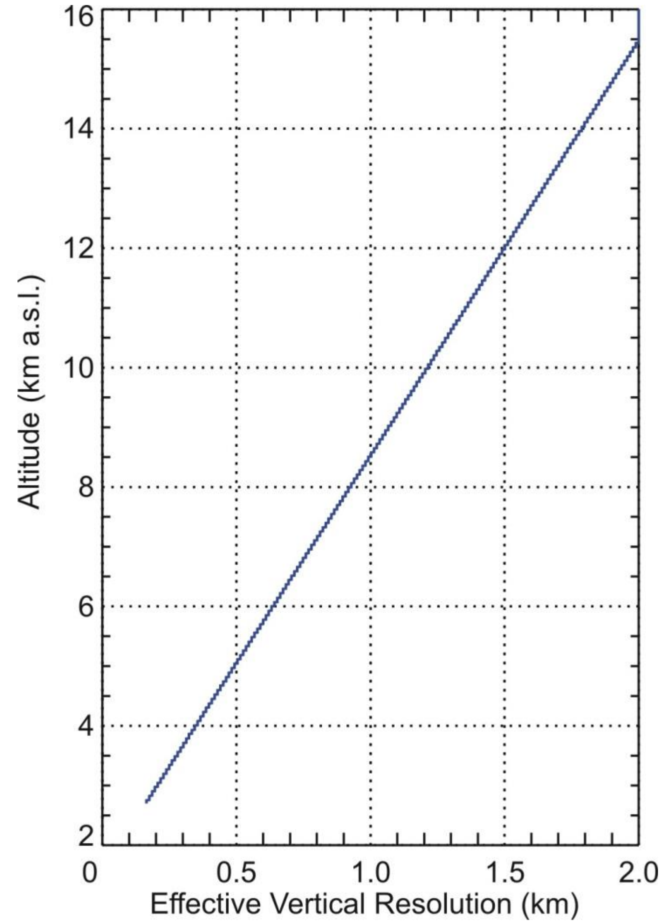


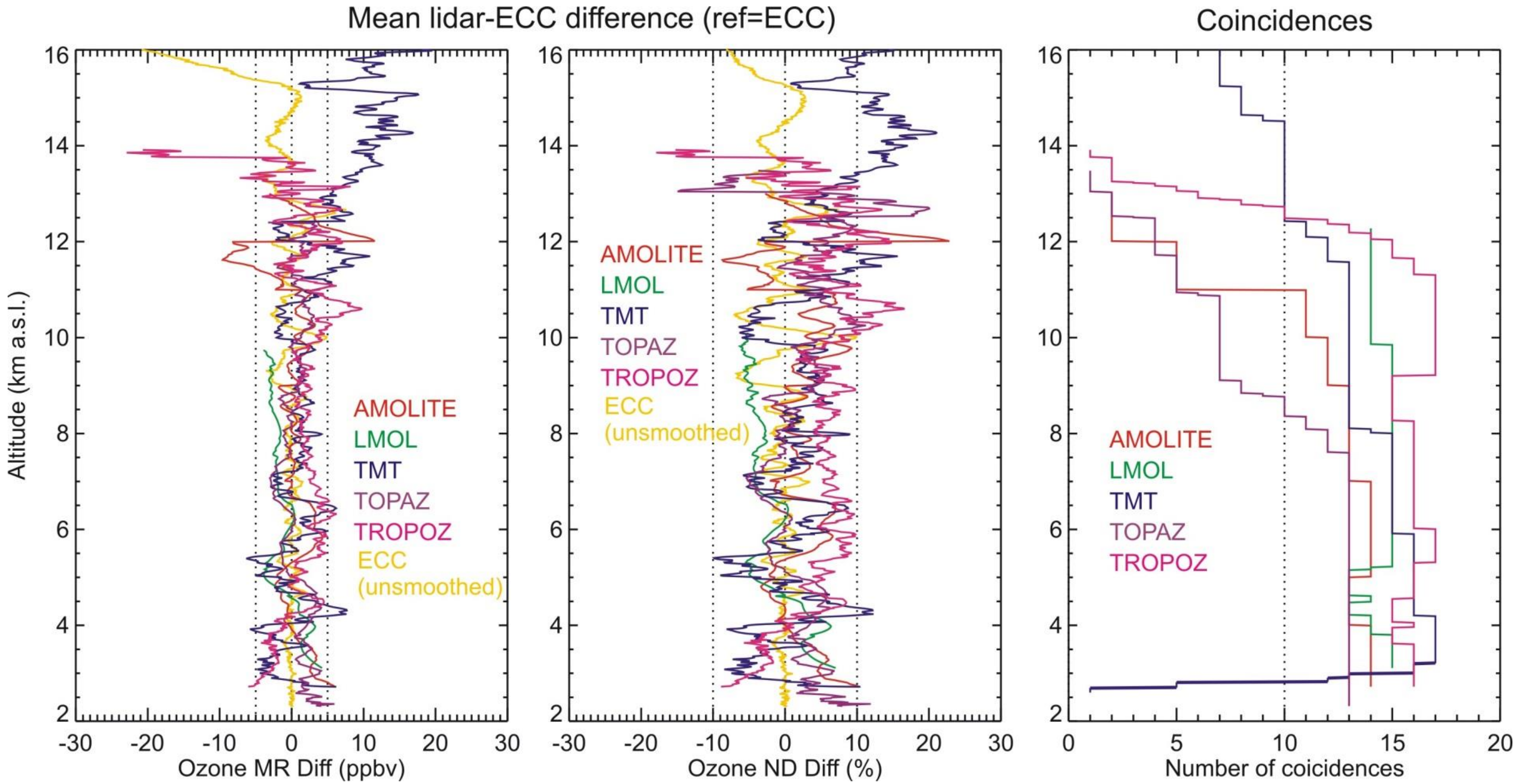
Figure shows SCOOP vertical resolution

- *Use NDACC-Standardized recommended definition (Leblanc et al., Atmos. Meas. Tech., 2016)*
- *200-m at the surface, 1.5 km at 12 km a.s.l.*
- *The actual averaging kernels (AK) are not identical for all lidars and ECC: they take into account each instrument sampling resolution (from 3.75 m to 15-m)*

➔ **Caveat: the quality of the profiles is NOT optimized for all lidar instruments (e.g., TMT near-field, details later)**

All coincidences, lidars vs. ozonesonde

One-to-one instrument comparisons composited together against ECC ozonesonde



All instruments:

- **Below 10 km: within 5 ppbv or 10% of each other**
- **A few exceptions above 10 km, due to poor stats (less coincidences) and possibly geographical mismatch**

This ends our "traditional approach"
to validate the TOLNet lidars

Now, let's use centralized data processing
for further validation

Why use Centralized Data Processing?

Several efforts made over the past 5-10 years towards centralized data processing for lidar networks:

EARLINET (aerosols), NDACC (ozone depletion), GRUAN (climate),
<u>and now TOLNet (AQ)</u>

Advantages:

Standardized processing

➔ *Maximizes comparability (for both products and their uncertainty)*

Robust processing

➔ *Facilitates Near-Real-Time delivery of homogeneous network-wide measurements*

Alternate to in-house processing

➔ *Facilitates identification and separation of instrumental and algorithm errors*

Caveats:

Standardized processing

➔ *Can lead to non-optimized results if network instruments are too heterogeneous*

Centralized processing

➔ *Potential to lose traceability if no effort for transparency is made*

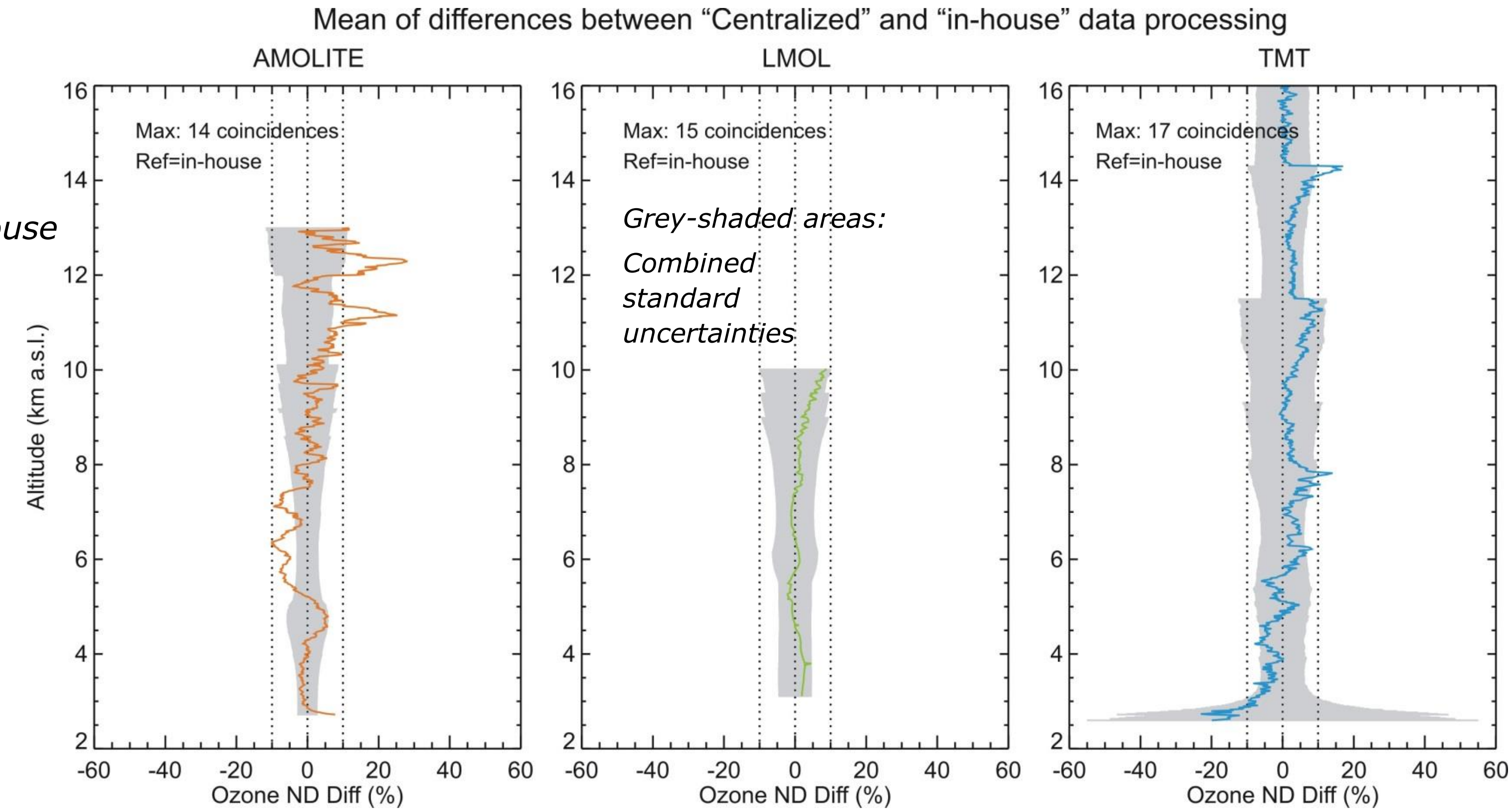
➔ **The rest of this work reports on the first (and preliminary) results from the TOLNet centralized data processing to compare and validate the TOLNet lidars**

Data Processing: Centralized vs. in-house

Preliminary assessment of the centralized data processing using AMOLITE, LMOL and TMT examples:

Figures shows

Differences between centralized and in-house are within +/-10% almost everywhere



➔ **+/-10% = Quite satisfactory considering the preliminary nature of both the centralized data processing results and the SCOOP Level 2 data**

➔ **Use of centralized data processing adequate enough to inter-compare the 5 TOLNet lidars' uncertainty budgets**

Comparing the uncertainty budgets

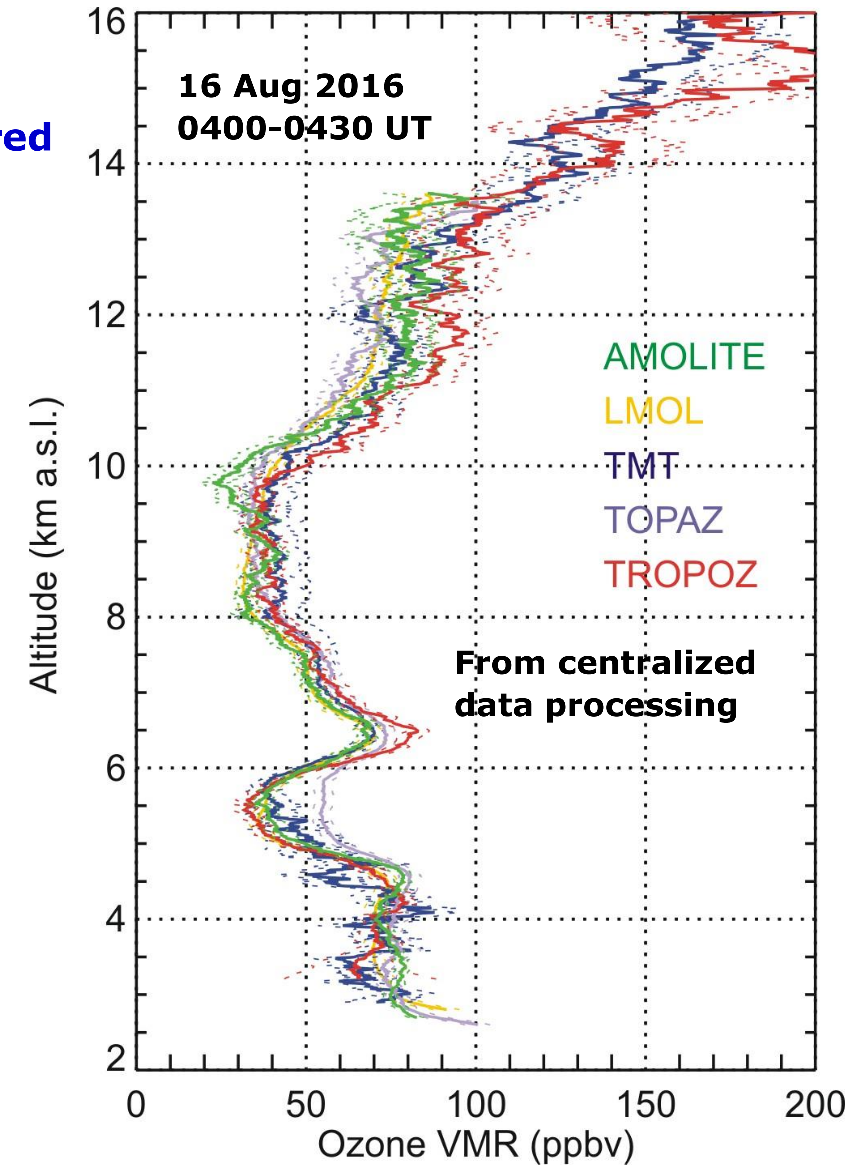
With centralized data processing, uncertainty budgets of all lidars can be compared on a common basis

Use of NDACC-recommended standardized uncertainty budget
(*Leblanc et al., Atmos. Meas. Tech., 2016*)

Figure shows one example:

- *30-min profile starting on Aug 16 at 0400 UT (nighttime)*
- *All lidars yield same vertical resolution*
- *Ozone MR with +/- uncertainty (thin dotted lines)*

➔ **Uncertainty budgets for these profiles will be shown next**

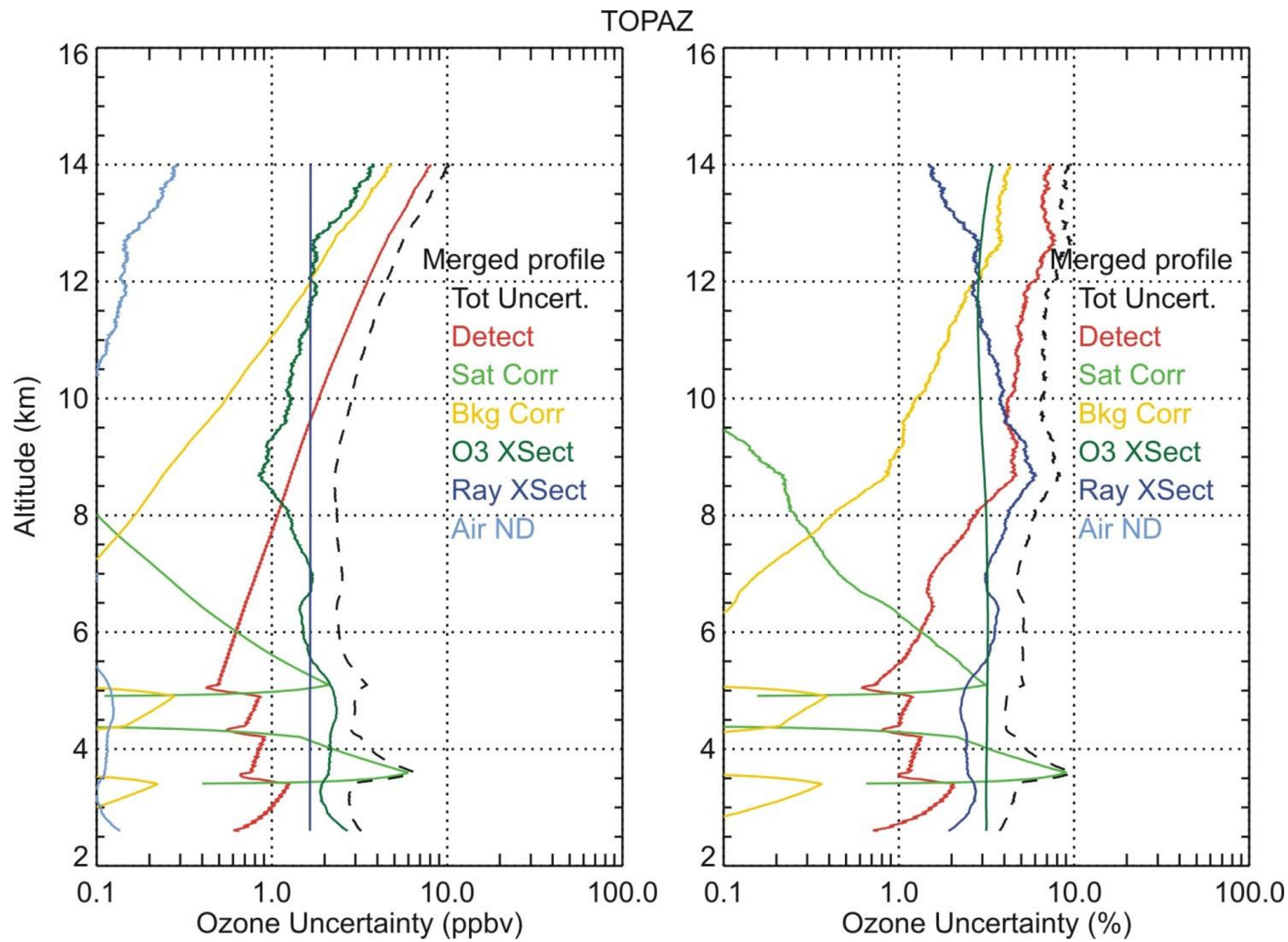


Uncertainty budget, TOPAZ example

TOPAZ example:

Figure shows:

- *6 uncertainty components (colored curves)*
- *Black dash curves show combined uncertainty*
- *4 different components have major impact on total uncertainty, at different altitudes*



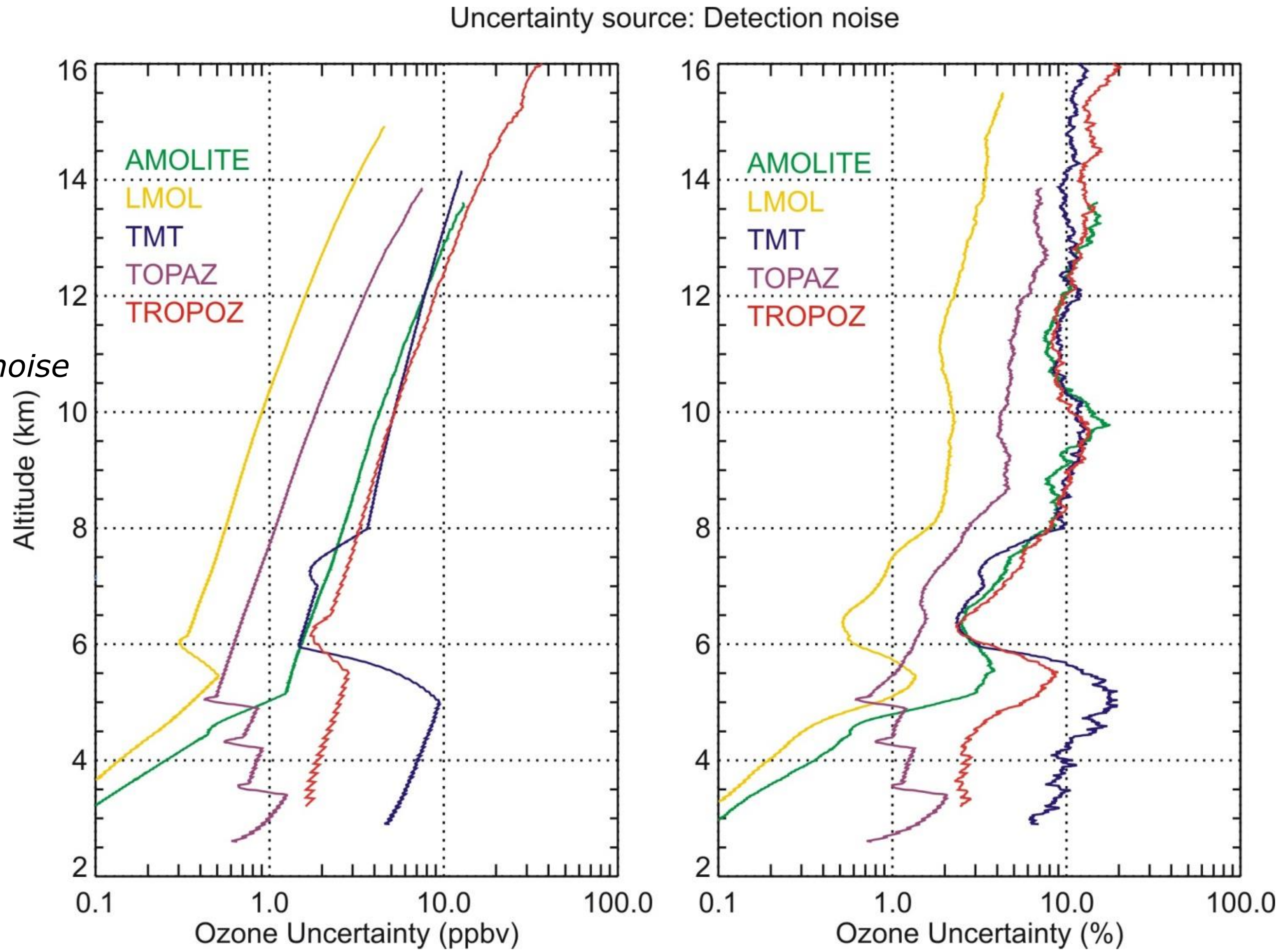
➔ Individual uncertainty components will be shown next

Uncertainty budgets comparison details

Detection noise:

Figure shows:

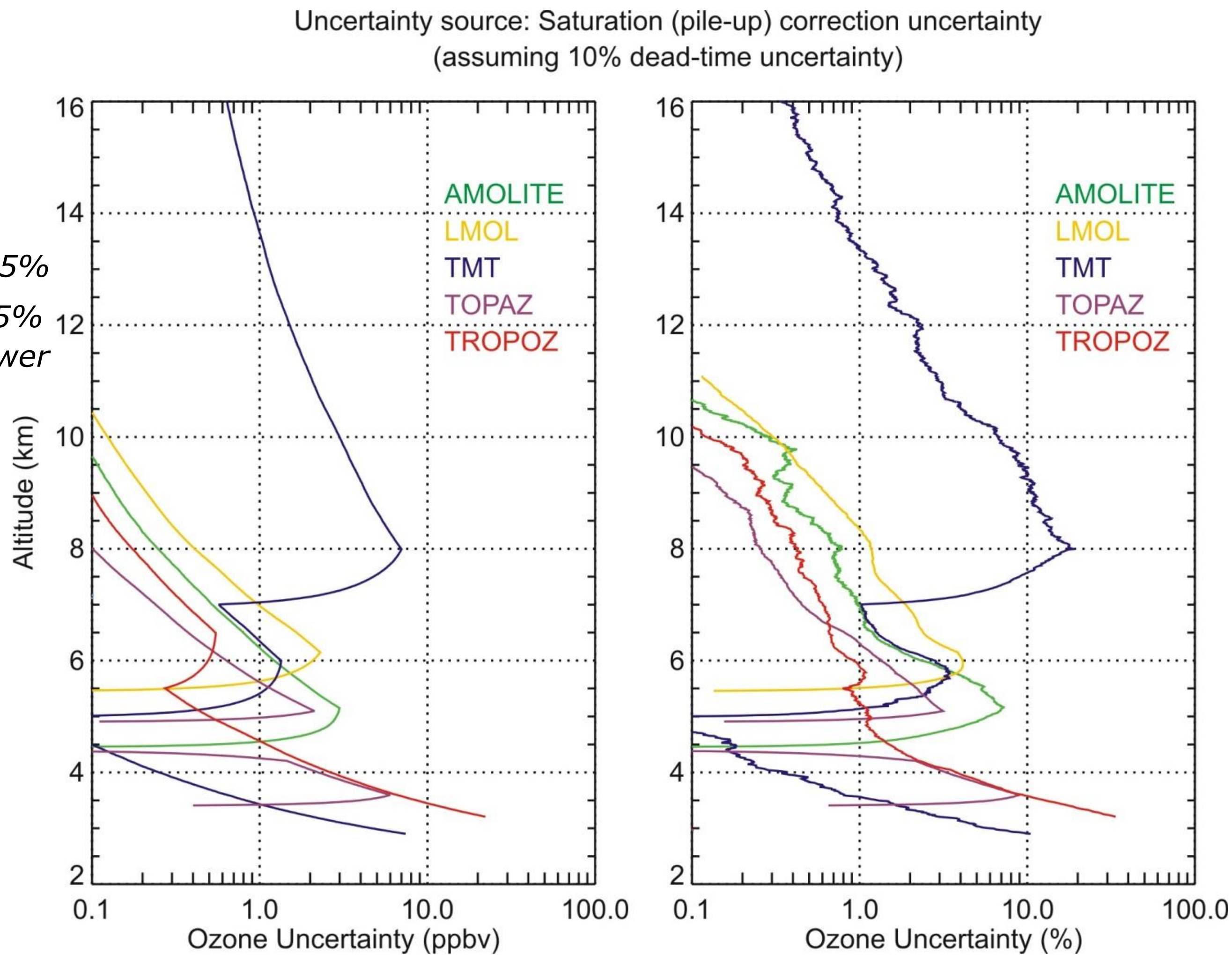
- *Large range of values*
- *Higher laser rep. rates (LMOL, TOPAZ) yield lower detection noise*
- *TMT detection noise uncert. highest for altitudes below 6 km due to inadequate SCOOP vertical resolution applied to near-field low STNR*



Saturation (pile-up):

Figure shows:

- *Values remain typically below 5%*
- *Exception for TMT, reaching 15% (strong signal optimized for lower stratosphere)*

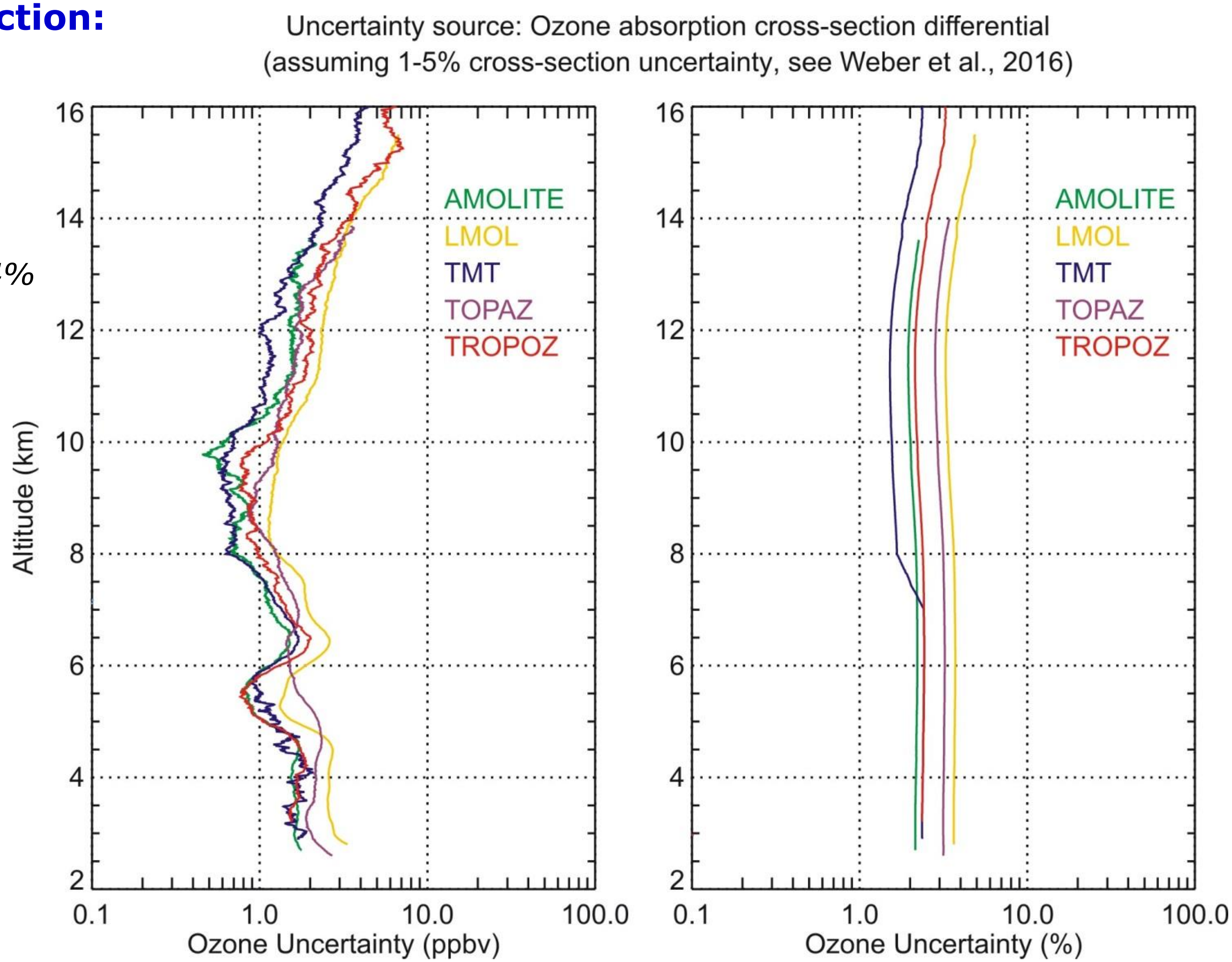


Uncertainty budgets comparison details (cont.)

O3 absorption cross-section:

Figure shows:

- *All lidars in the order of 2%-4%*
- *2%-4% is the minimum uncertainty we should expect from all instruments*



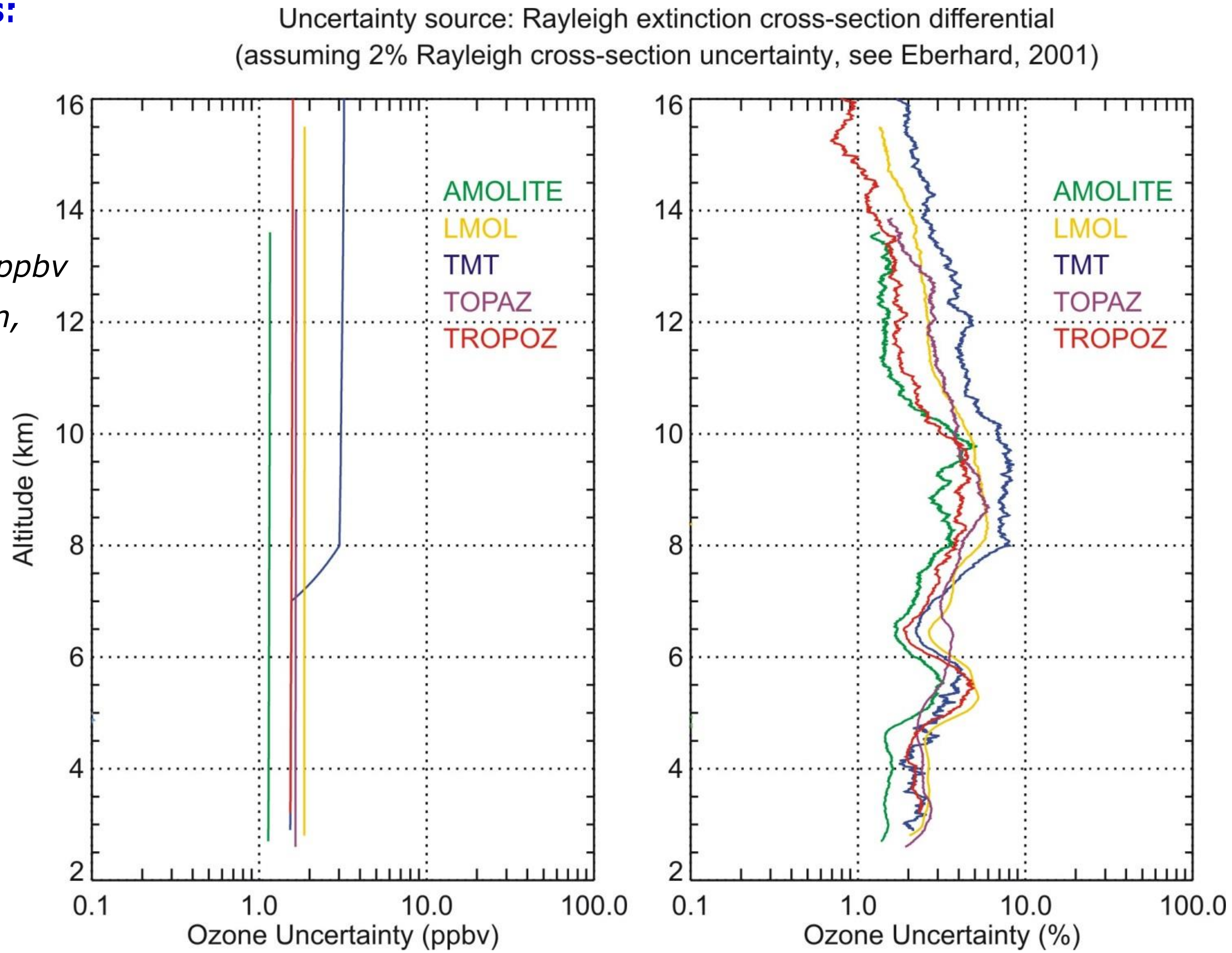
Ref: Weber, M., et al.: Uncertainty budgets of major ozone absorption cross sections used in UV remote sensing applications, Atmos. Meas. Tech., 9, 4459-4470, 10.5194/amt-9-4459-2016, 2016.

Uncertainty budgets comparison details (cont.)

Rayleigh cross-sections:

Figure shows:

- *All lidars: in the order of 1-2 ppbv*
- *Exception for TMT above 8 km, in this case due to the use of a 299/355 nm DIAL pair*



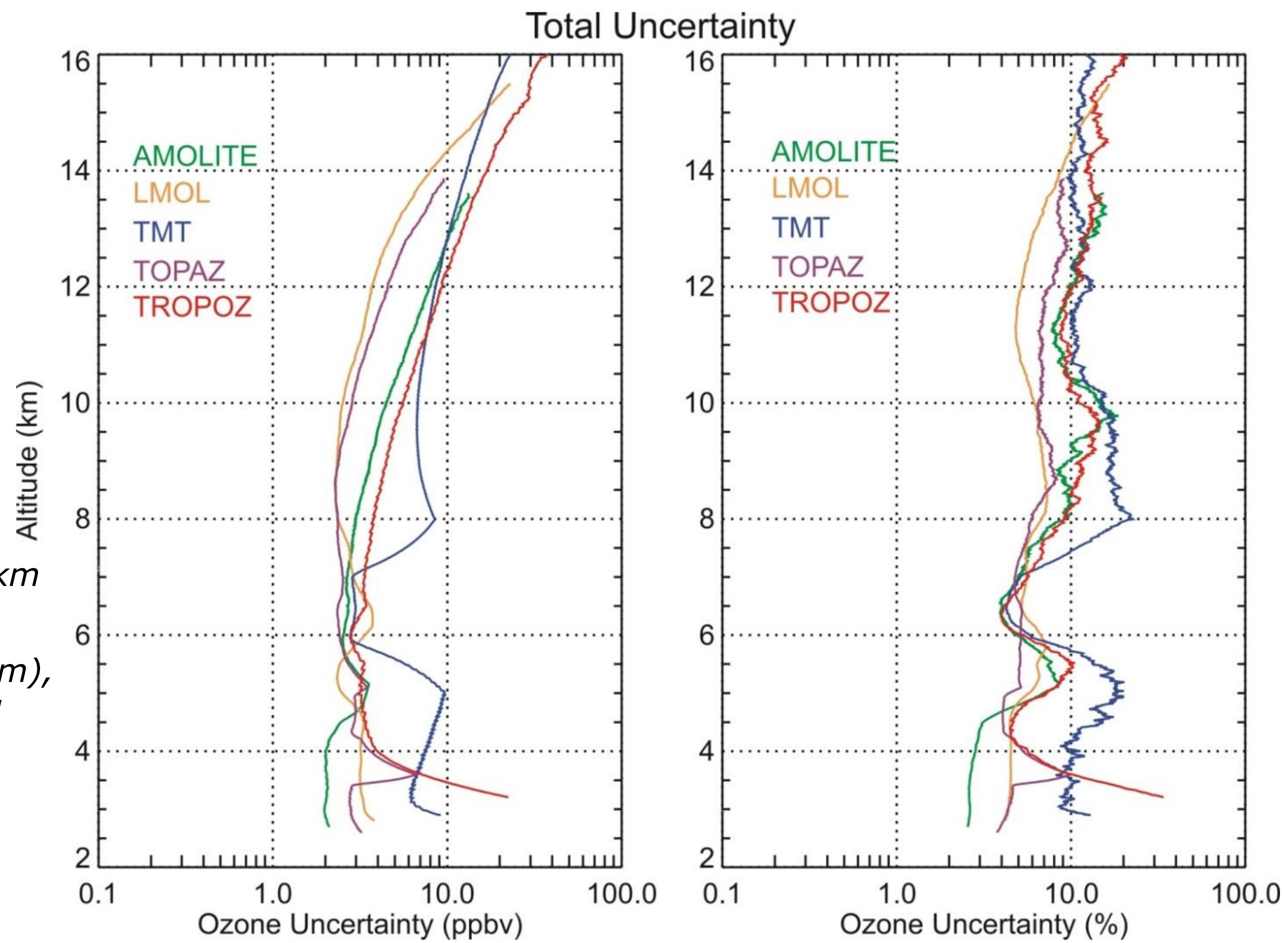
Eberhard, W. L.: Correct equations and common approximations for calculating Rayleigh scatter in pure gases and mixtures and evaluation of differences, Appl. Opt., 49, 1116-1130, 10.1364/ao.49.001116, 2010.

Total uncertainty

Total uncertainty, all 5 lidars:

What the figure shows:

- *Total uncertainties range between 2 ppbv/2% and 4 ppbv/10% for all lidars below 12 km*
- *Exception is for TMT, with localized peaks at 5 km and 8 km*
- *TMT higher uncertainty due to low STNR in the near-field (5 km), and inadequate SCOOP vertical resolution forcing transition to far-field in a region of strong signal saturation (8 km)*



➔ All uncertainty estimates match very well the lidar-lidar and lidar-sonde differences observed during SCOOP

➔ Present budget also highlights the need to apply instrument-dependent vertical resolution schemes in order to optimize final product ➔ SCOOP Data Level 3 !...

Summary and Perspectives

- **SCOOP campaign took place Aug 10-16, 2016**
- **Objective was to validate the tropospheric ozone measurements of 5 of the 6 TOLNet lidars**
- **Campaign was very successful: 5 x 50+ hours, 18 ozonesonde launches**
- **All preliminary ("Level 2") lidar data were validated beyond expectation**
- **Lidar-lidar and lidar-sonde show differences not exceeding 10% in most cases and at most altitudes below 12 km**
- **Centralized data processing confirmed that observed differences remain within all reported uncertainties**
- **TOLNet centralized data processing algorithm development will continue, in parallel with the refinement of the in-house algorithms**
- **TOLNet is now ready to produce optimized SCOOP Level 3 data, with nominal vertical resolution, and standardized uncertainty budgets**
- **"Level 3" data will be publicly available and used for science studies**

THANK YOU

Thank you to the 1,000 Firefighters who saved the community of Wrightwood, CA on the day the SCOOP Campaign was cut short due to the BlueCut Fire Evacuation

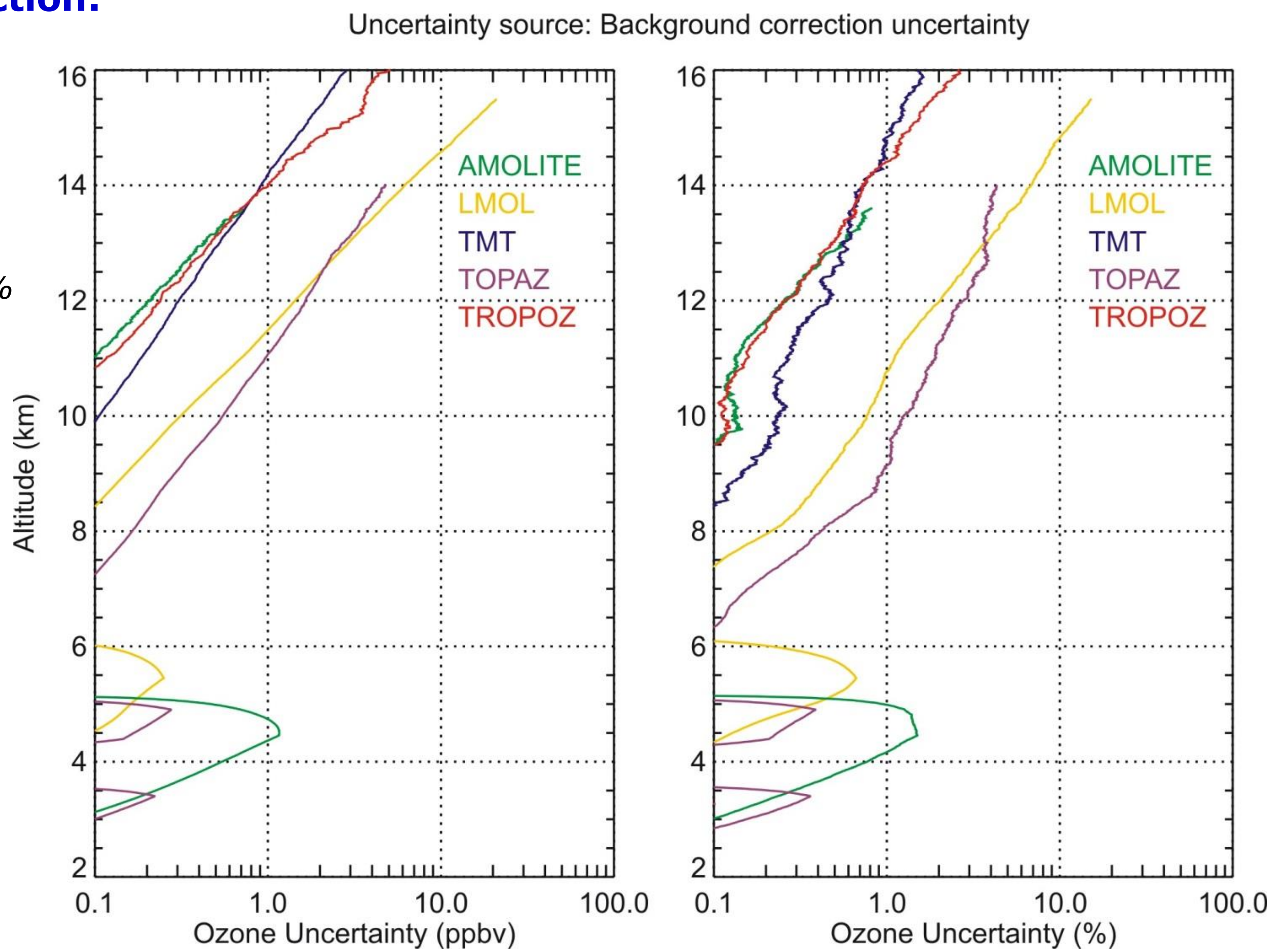
BACK UP SLIDES

Uncertainty budgets comparison (cont.)

Background noise extraction:

Figure shows:

- *All remain below 2%*
- *Exception for TOPAZ up to 4% at highest altitudes*

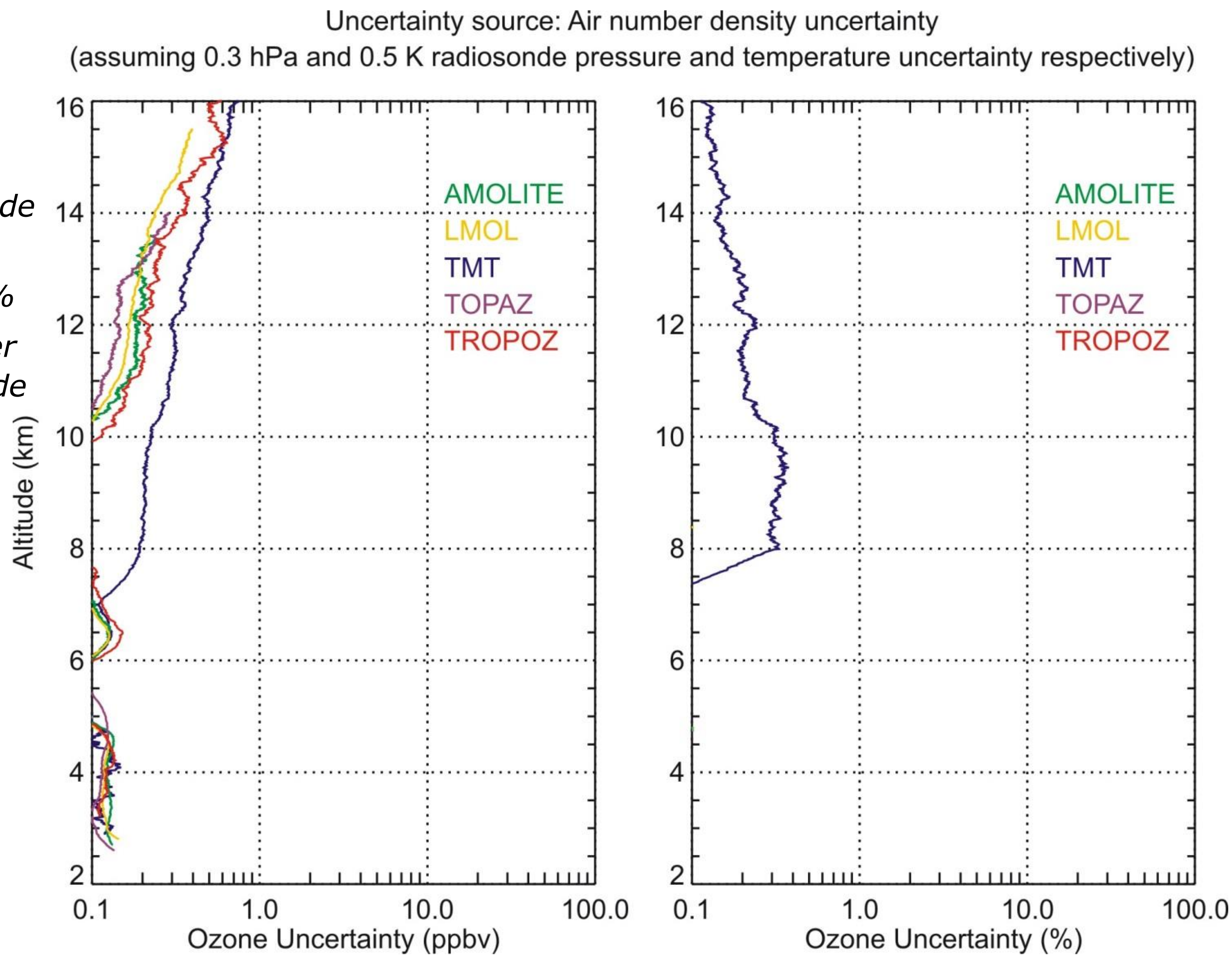


Uncertainty budgets comparison (cont.)

Air number density:

Figure shows:

- *Best case scenario: use of sonde temperature and pressure*
- *All lidars below 1 ppbv or 0.3%*
- *Expect estimate to be 4x larger if using models instead of sonde*



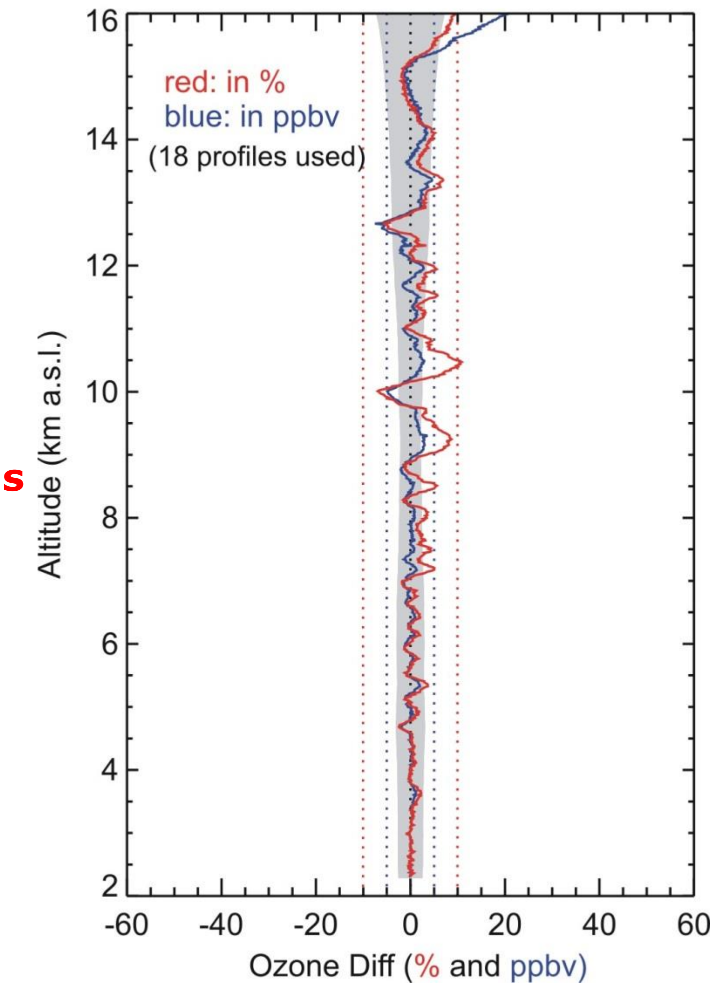
Smooth and unsmoothed profiles

Difference between ECC with and ECC without AKs provides a measure of additional noise to expect when vertical resolution is not standardized

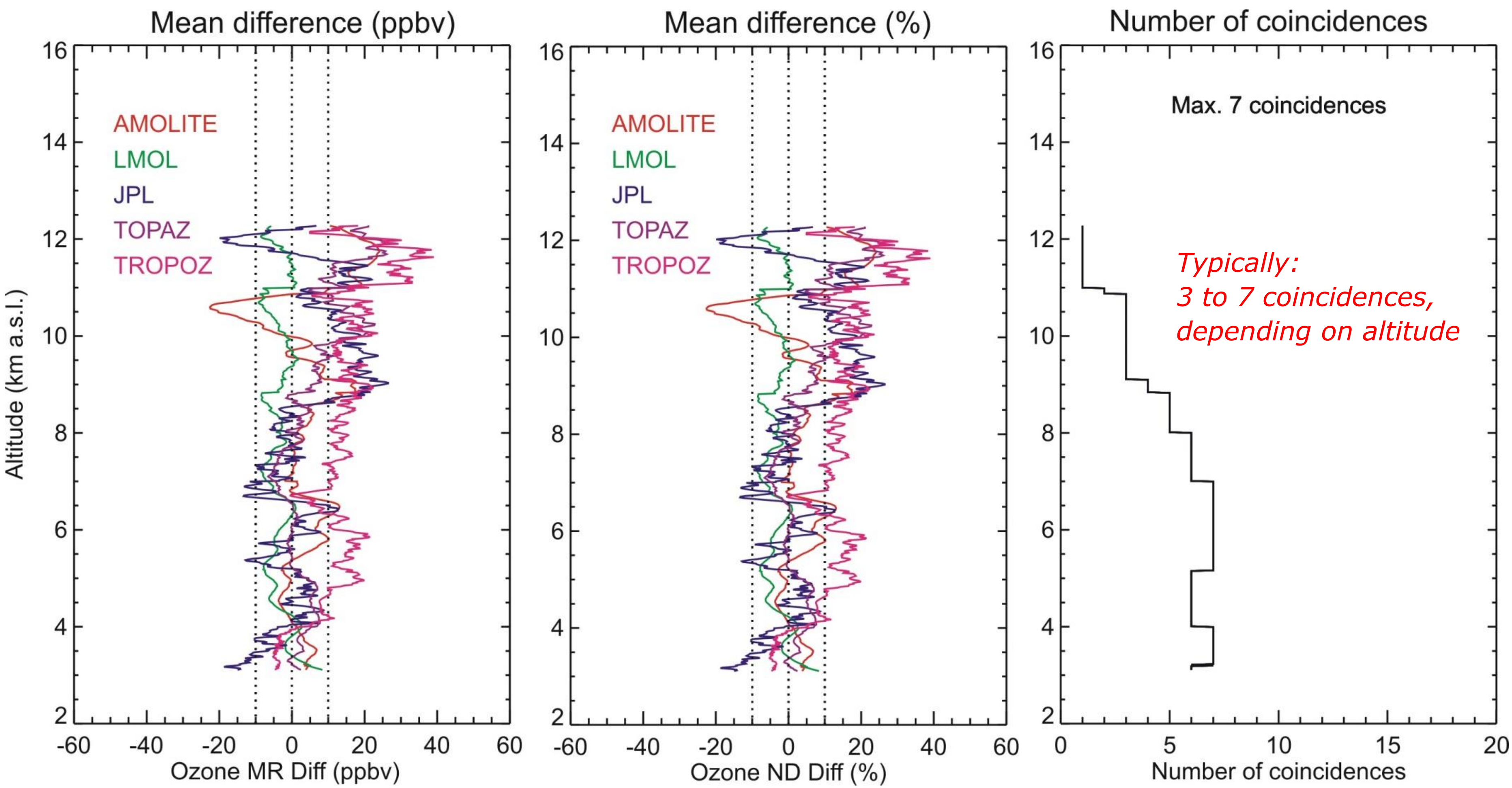
➔ **With the SCOOP vertical resolution scheme, we spare ourselves an additional +/-5 ppbv or +/-10% additional noise in the comparisons**

➔ **But…**
It must be pointed out that any inaccurate computation of a prescribed resolution may result in this additional noise

Mean ozone difference between ECC with and without Averaging Kernels



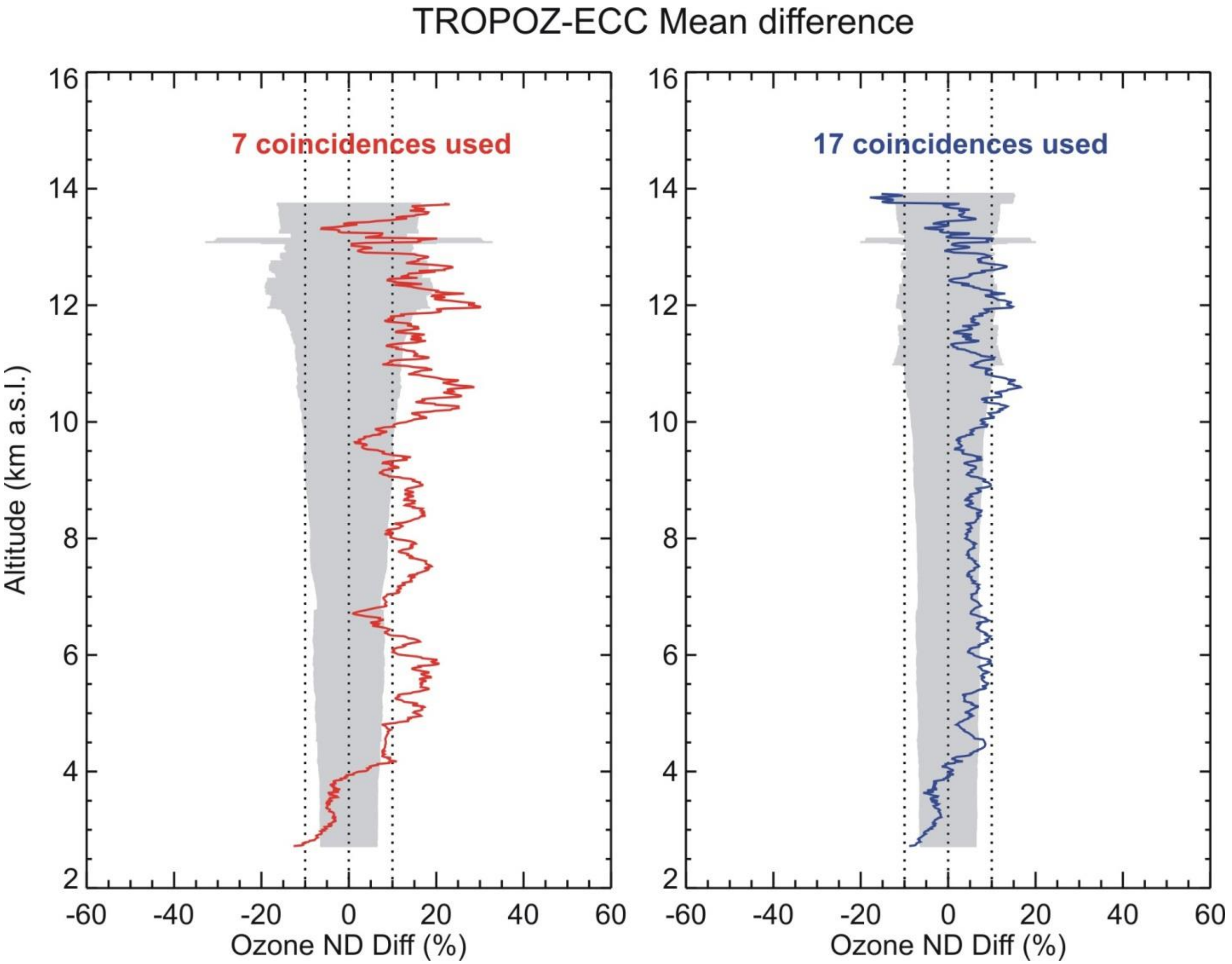
All-lidars comparisons with ECC ozonesonde



- **Only 7 coincidences, at most, with ALL 5 lidars operating simultaneously**
- **All lidars within +/-10% of ozonesonde**
- **TROPOZ 10-15% high bias not representative (see next slide)**

Sampling size and representativeness

TROPOZ-ECC differences show different behavior, depending on number of coincidences used



➔ **Choosing to compare all datasets against each other is a good thing only when sampling size is large enough to afford good statistics**

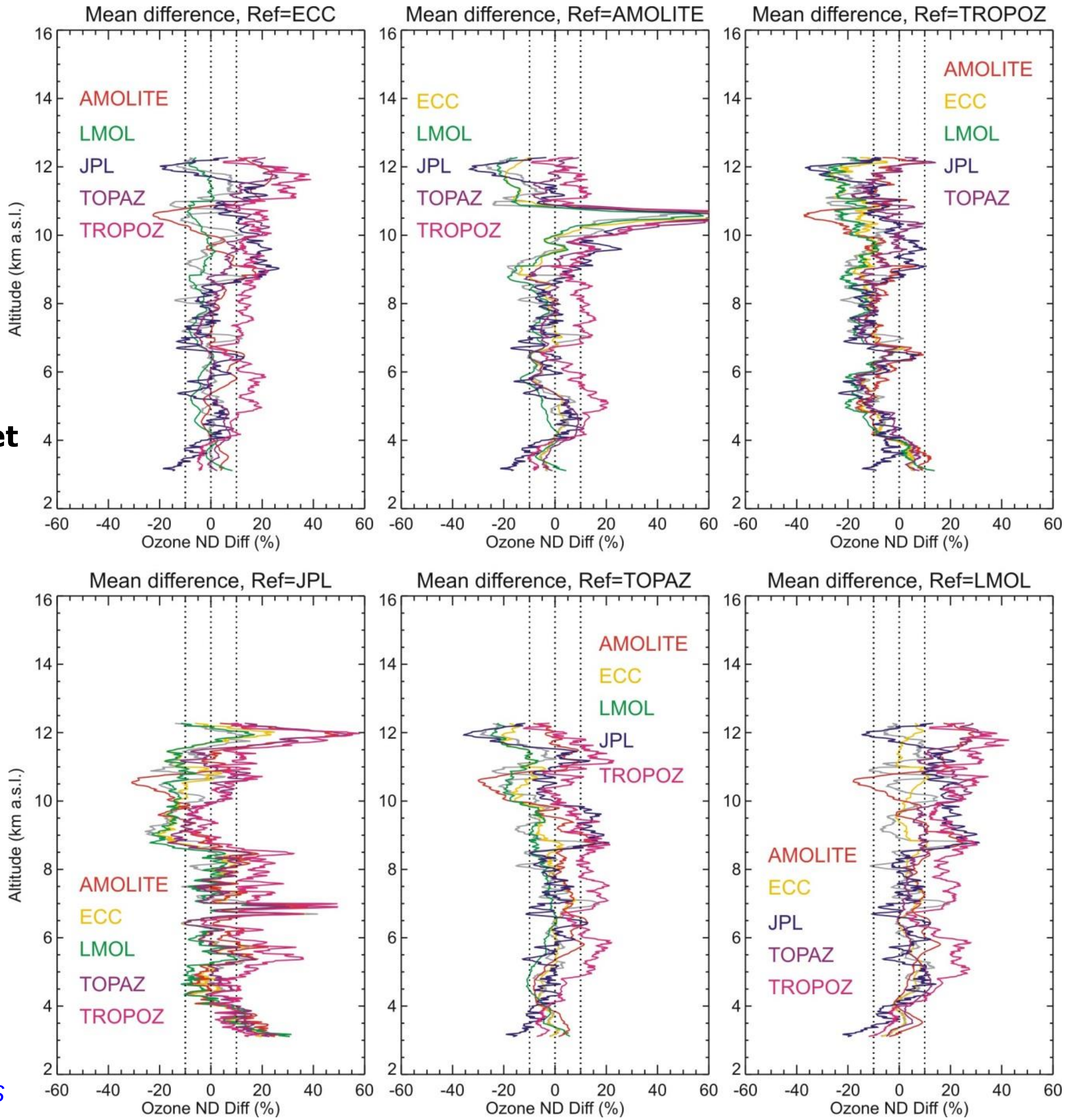
Red apples and red apples, but only 7 of them

All-lidars and ECC, exact same times for all (4-7 coincidences)

Each figure shows all other datasets with respect to one reference dataset

- *Number and times of coincidences are identical for all dataset pairs*
- *Very low number of coincidences for altitudes above 10 km*

➔ *Results above 10 km have a low degree of significance (basically = ignore them)*



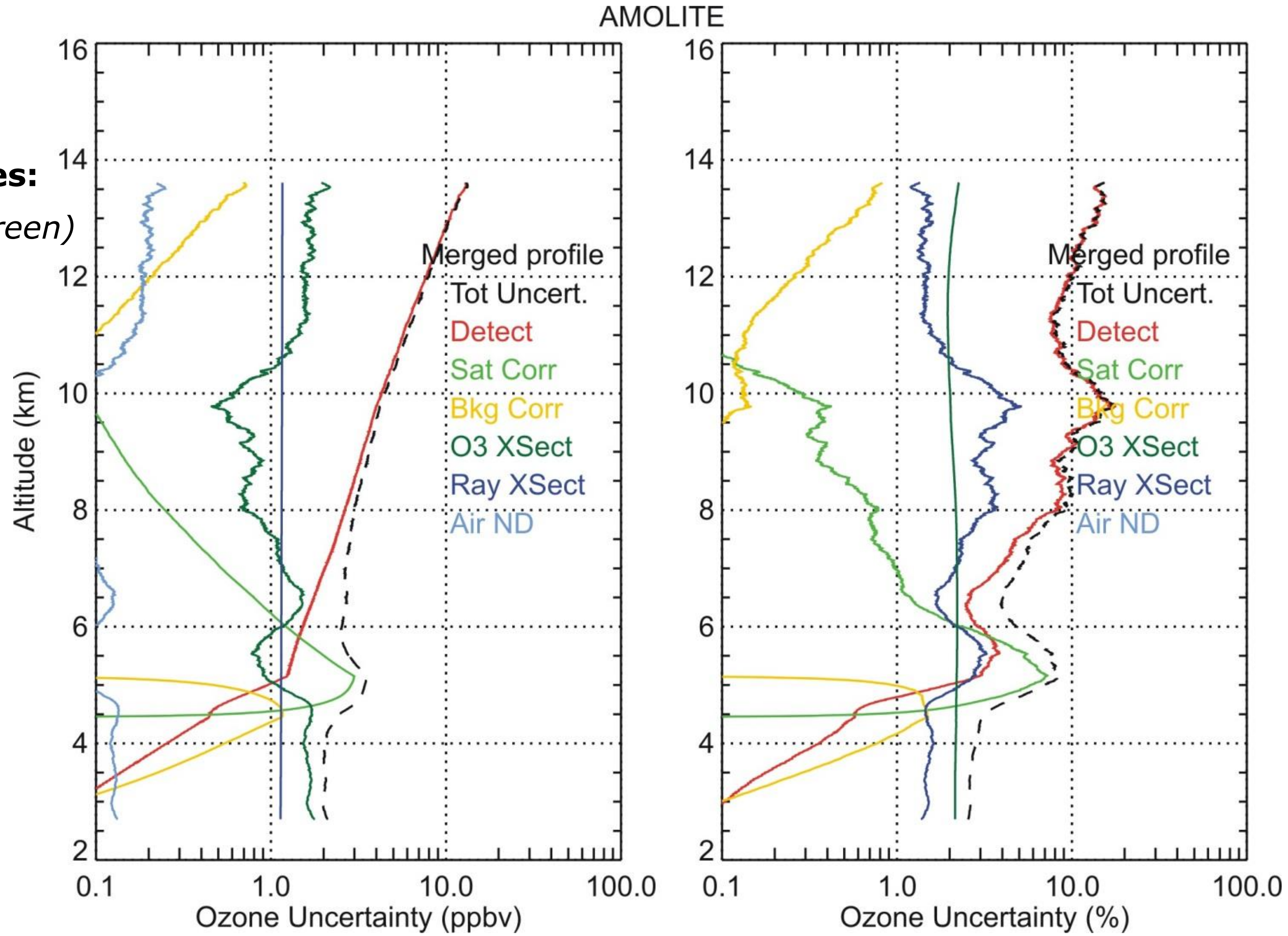
AMS

AMOLITE case:

Dominant uncertainty sources:

- *Ozone cross-sections (dark green) below 4 km*
- *Saturation (light green) at 5 km*
- *Detection noise (red) 6 km and above*

Black dash curves show combined total uncertainty



Uncertainty budgets for AMOLITE can be directly compared to other lidars by scrolling through next 4 slides

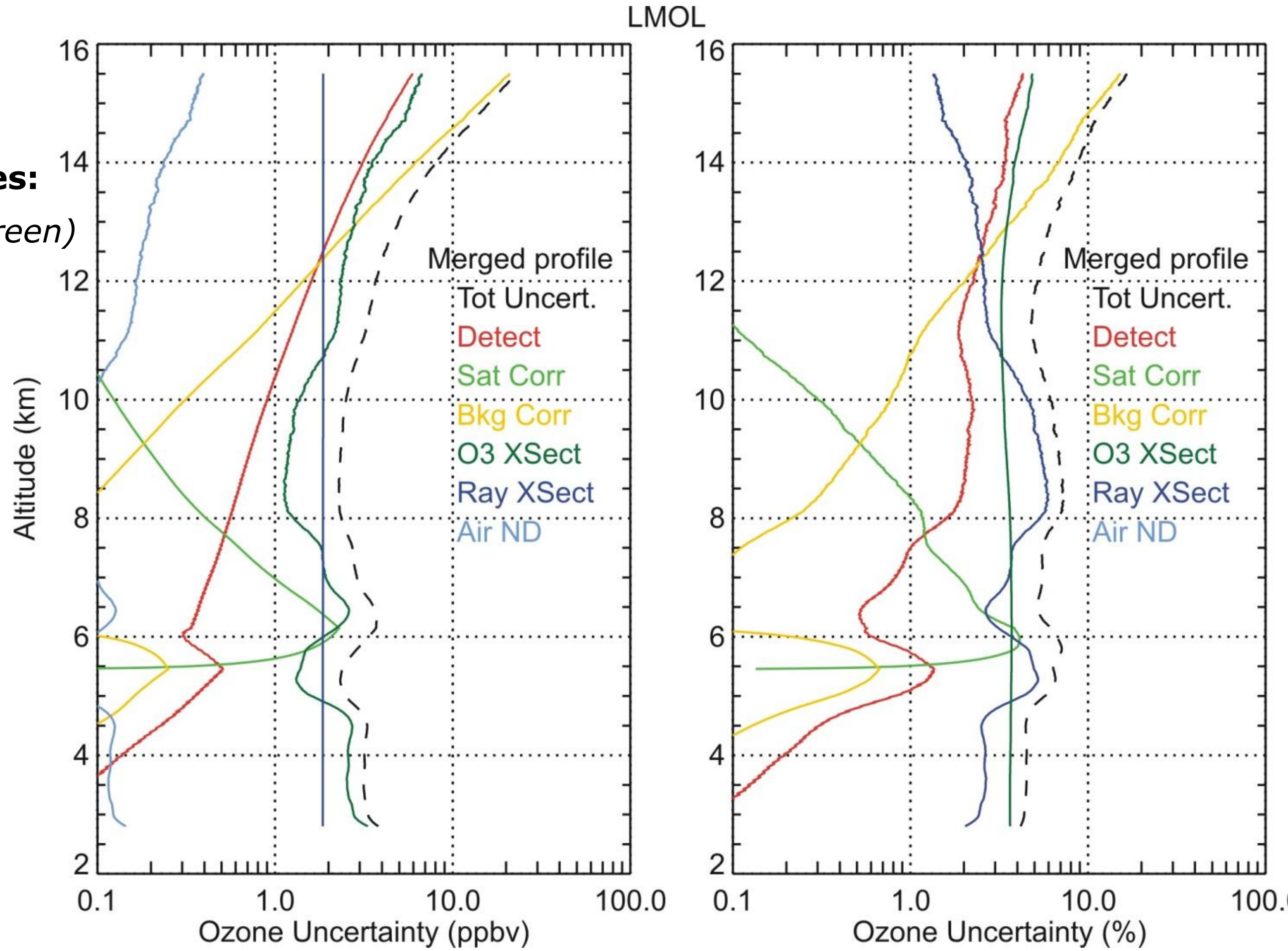
Application 3: Uncertainty budget (cont.)

LMOL case:

Dominant uncertainty sources:

- *Ozone cross-sections (dark green) Mainly below 5 km*
- *Saturation (light green) at 6 km*
- *Rayleigh extinction cross-section (blue) Below 12 km*
- *Background noise extraction (yellow) Above 12 km*

Black dash curves show combined total uncertainty



Application 3: Uncertainty budget (cont.)

TMT case:

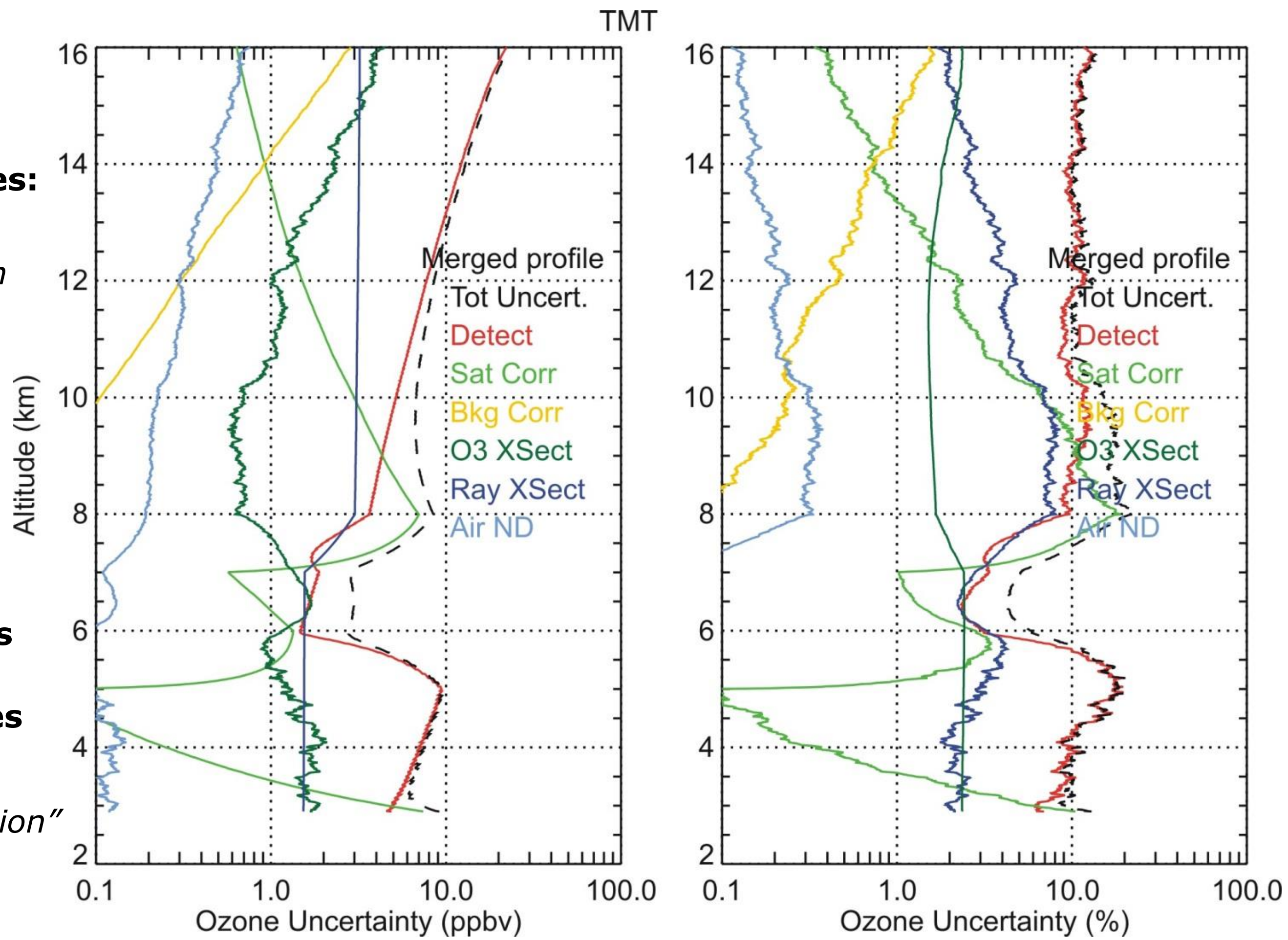
Dominant uncertainty sources:

- *Detection noise (red)*
  Almost everywhere near 8 km
- *Saturation (light green)*
  at 8 km

Black dash curves show combined total uncertainty

Total uncertainty for TMT is higher than other lidars, especially at lower altitudes

- *Lower STNR for near-field*
- *Inadequate "SCOOP resolution"*



➔ SCOOP vertical resolution not well suited for TMT. Unlike the other TOLNet lidars, this lidar is optimized for altitudes above 4 km, nighttime and long-term monitoring

Application 3: Uncertainty budget (cont.)

TROPOZ case:

Dominant uncertainty sources:

- *Saturation (light green) below 4 km*
- *Detection noise (red) Above 4 km*

Black dash curves show combined total uncertainty